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Preliminary Report on the Field Testing of an Air-Curtain Screen to Minimize Fish Passage onto Submerged Floating Drydocks

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

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CASCADE GENERAL
PORTLAND SHIPYARD

Preliminary Report on the Field Testing of an Air-Curtain Screen to Minimize Fish Passage onto Submerged Floating Drydocks

Prepared for:

NSRP Environmental Studies and Testing Panel, SP-1
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Summary

Numerous runs of West-Coast anadromous fish are now listed as threatened or endangered under the Endangered Species Act (ESA). The operation of floating drydocks can result in the stranding of protected fish, which is a violation of the "take" prohibitions in section 9 of the ESA.

This study is focusing on the testing and evaluation of using an air-curtain screen as a deterrent to the passage of fish onto a submerged floating drydock. The effects of water approach velocities during drydock flooding are also being considered.

To date, 14 separate tests have been performed using an operational floating drydock at the Cascade General, Inc facility located in Portland, Oregon. The drydock has been outfitted with a piping system that creates a continuous air-curtain around the perimeter of all areas open to the surrounding water body during submergence. Tests are alternately conducted by submerging the drydock with the air curtain on and off, and collecting data on the number of fish observed through electrofishing and visual surveys.

The preliminary results indicate that the efficacy of the air-curtain screen may be species specific, and be controlled by environmental factors such as time of day and artificial lighting. In some cases, fish passages were observed to drop significantly as a result of the air curtain, while in others, the air curtain seemed to encourage fish passage. The air curtain does seem to be an effective barrier to juvenile salmonids and other anadromous fish, which are the subject of the ESA listings. Most species attracted to the air curtain are generally considered to be game fish and have no ESA protection. Further testing is required to fully evaluate the efficacy of the air-curtain screen for application on floating drydocks.

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INTRODUCTION

This report presents the study methodology and preliminary findings, conclusions, and recommendations for the field testing of an air-curtain screen intended to serve as a barrier to the movement of fish into the area of a submerged floating drydock. An air-curtain screen consists of a near vertical wall of air bubbles deployed around the deck of a submerged drydock. In this study, the air-curtain screen was established by continuously injecting air into a system of perforated PVC pipes attached to the drydock.

The findings of this study are considered preliminary. Additional field testing is necessary to fully evaluate the efficacy of the air-curtain screen and the performance effects of varying operating parameters.

BACKGROUND

The operation of floating drydocks can result in the stranding of fish when the dock is raised following submergence. This occurs when fish move from the surrounding water body into the area of the submerged drydock, either by swimming or by being trapped in the flood current as the dock sinks. When the dock is raised, the fish can become stranded if they are not washed from the deck area by the receding current. Mortality rates of stranded fish, particularly juveniles, can be high due to entrapment in drainage systems, impingement on dock structures, and stress.

Numerous runs of West-Coast anadromous fish, ranging from British Columbia to Southern California, are now listed as threatened or endangered under the Endangered Species Act (ESA). The National Marine Fisheries Service (NMFS) published its 4(d) rule in July 2000 for the protection of several listed stocks of Pacific Northwest salmon and steelhead. Stranding of listed juvenile or adult fish during drydock operations constitutes "take[1]" under the rule, and is a violation of Section 9 of the ESA. Taking of listed fish is subject to civil and criminal penalties, and citizen lawsuits.

Sections 7 and 10 of the ESA provide mechanisms for operators of drydocks to receive protection from liability under the ESA for incidentally taking a listed species. Section 7 requires all federal agencies to consult with NMFS on any project that may jeopardize a listed species, and implement mitigating measures. Therefore, if a federal connection to the drydock operation triggers a consultation, then mitigating measures can be developed that allow for incidental take under section 7. If a federal connection does not exist, parties may receive a permit for incidental take under section 10. Section 10 incidental take permits require the submittal of a Habitat Conservation Plan and the proposal of mitigating measures to minimize taking listed species.

[1] The term "take" under the ESA means to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect a listed species, or attempt to engage in any such conduct.

An effective measure is required that controls the movement of fish into the drydock area, but that does not interfere with docking or undocking operations. This study is evaluating the use of air-curtain screens for creating a barrier to the movement of fish into the dock area during submergence to minimize stranding. If a design is shown through this study to be measurably effective at preventing stranding, air-curtain screens could be applied at shipyards located in areas with listed fish to avoid take, or in seeking an incidental take permit under Section 10 of the ESA.

Several systems are commercially available for blocking or repelling the passage of fish into submerged drydock areas. Such systems include electric fields, strobe lights, sonics, and air curtains. The principles of each of these systems are summarized below. Physical barriers such as nets and hanging chains were not considered, as they are not conducive for use with floating drydock operations.

Electric Fields

Electric field barriers block or repel fish from entering a controlled area by establishing an electric field pattern in the water column. When fish enter the field they become part of the electrical circuit. The current passing through the fish evokes reactions ranging from slight discomfort to full paralysis. The fish is either repelled by the discomfort or swept clear of the area by the surrounding water current once paralyzed. Electric barrier systems require the installation of an electrode array and control system.

Strobe Lights

Strobe light systems use an array of underwater flashing lights to disturb or scare fish into leaving a controlled area. The response of fish to strobe lights varies with species, life stage, and water conditions. Generally, strobe lights are deployed in combination with some other barrier system.

Sonics

Sonic systems use underwater sound projectors to produce a high intensity sound underwater. The systems can be used to repel target species of fish using combinations of frequencies. Sonic systems are also used in combination with air curtains.

Air Curtains

Air curtains establish a bubble plume in the water column intended to startle and confuse fish to deter them from entering a controlled area. Air curtains require the installation of delivery piping and a source of compressed air.

The air curtain screen was selected for field testing because of the low construction cost and ease of operation, it is rugged and repairable, and because it can be easily modified or augmented with other barrier systems.

SCOPE

The scope of the study included the following:

1. Design and install an air curtain piping system on an operational floating drydock.

2. Conduct 14 controlled tests to evaluate the efficacy of the air curtain at deterring fish passage.

3. Conduct measurements of water approach velocities under two drydock operating scenarios.

4. Collect data on the physical operating parameters of the system (e.g. required air flow).

APPROACH

Field testing of the air-curtain screen was conducted using a floating drydock at Cascade General, Inc.'s facility located in Portland, Oregon. The test consisted of designing and installing a piping system to create an air curtain around the open deck of the drydock, and sinking the dock multiple times with the air curtain on and off to collect data on the number of fish entering the submerged area. Testing began in April 2000, and the latest test was conducted in September 2000. Testing was performed under the authority of a scientific take permit issued by the Oregon Department of Fish and Wildlife.

System

Drydock 4 at the Portland Shipyard was used to conduct the testing. The drydock is 982 feet long, 192 feet wide (inside), and has a maximum draft of 39 feet over the pontoon deck.

The piping system for the air-curtain consisted of two-inch diameter schedule 80 PVC pipe. The pipe was attached to the pontoon deck of the drydock around the perimeter of all areas open to the surrounding water during submergence. Approximately 500 feet of piping was installed. Holes measuring 3/32 of an inch in diameter were drilled in the PVC pipe every six lineal inches. The hole spacing was later reduced to one per every lineal foot of pipe by plugging alternate holes with sheet metal screws.

Each end of the PVC pipe was fitted with a one-inch diameter quick-release coupling and attached to a flexible air line. Compressed air was supplied to the piping by the facility's compressors.

Testing

A total of 14 tests were conducted during the months of April, June, and September. The tests were repetitive, and were conducted on an empty drydock. Each test consisted of sinking and raising the drydock with the air curtain either on or off, conducting an electrofishing survey within the submerged drydock, and conducting a visual survey of the pontoon deck once the drydock was raised. Data on the numbers and types of fish sighted were recorded. Electrofishing and data collection were performed by a fisheries biologist with Ellis Ecological Services of Estacada, Oregon.

During each test, the drydock was submerged until flooded with 30 feet of water over the deck. This position was held for 30 minutes, then the dock was raised until 8 feet of water remained over the deck. An electrofishing survey was then performed within the drydock area using a boat. The electrofishing boat followed the same pattern of movement for each survey. Following the survey, the drydock was raised with approximately two feet of forward trim to drain the receding water toward collection sumps outfitted with fish baskets. The entire deck of the drydock was then inspected for fish.

Measurement of Water Approach Velocities

During the initial stages of field testing, fish were visually observed trapped within the flood current as the drydock was submerged. As a result, the engineering firm of Dames and Moore was retained to measure the approach velocities of flood water as the drydock was submerged. The velocity measurements were used to test the effects of varying the rate of submerging the drydock on the number of fish observations.

Water velocities were measured during two drydock descents. The descent rates were:

1. Normal – the drydock is submerged at a rate typical for normal safe and efficient operation.

2. Slow – the drydock is submerged at the slowest practical rate.

The measurements were taken using a single velocity meter suspended at approximately mid-depth in the flow just outboard of the air curtain piping system. The drydock was empty during the test.

FINDINGS

System Performance

The air curtain established on the drydock was approximately two-foot wide, and consisted of a continuous wall of tightly grouped bubbles of various sizes. The air curtain remained vertical or nearly vertical during slow descents, and when the drydock was stationary. During normal descents, the air curtain drifted as much as 45 degrees from vertical, and became dispersed. Between 2,000 and 2,400 cubic feet per minute (cfm) of air was required to maintain an adequate curtain. At flow rates much below 2,000 cfm, the air curtain became discontinuous and began to oscillate along the piping system.

Fish Observations

A total of 866 fish were sighted during the 14 surveys. Ninety-nine (99) of the fish were observed in the study area when the air-curtain screen was operational. Seven hundred sixty seven (767) fish were observed in the study area when the drydock was submerged without the air-curtain screen operating. A summary of the fish observations made during the tests is provided in Appendix A. Calculations made with these data are summarized in Appendix B.

Table 1 summarizes the observation results by date. The largest number of fish was observed on September 1st during tests 12, 13, and 14, with a total of 787. This test date happened to coincide with the migration of juvenile American shad in the Willamette River, significantly increasing the number of fish in proximity to drydock 4. The second highest number of fish observations occurred on April 25th, with a total of 43. Testing on April 25th was conducted at night. The total number of remaining fish observations occurring over four separate days of testing was 37.

Table 1. Summary of total fish observations in submerged drydock area with air curtain on and off.

	Date							
	4/11/00	4/12/00	4/13/00	4/20/00	4/25/00	6/25/00	9/1/00	Total
Observations-Air On	5	0	1	7	26		60	99
Observations-Air Off	2	5	6	9	17	0	726	767
Total	7	5	7	16	43	0	786	866

Most of the fish observed during the testing were juveniles, regardless of species. One mature chinook salmon and one mature steelhead were observed during the testing.

Table 2 provides selected ratios of fish observations made during tests with the air curtain on and off. The ratios are expressed as percentages, and were computed by dividing fish observations with the air curtain on and off by the total of the observations. The percent change for a set of observations was calculated by subtracting the quotient of the observations with the air curtain on and the observations with the air curtain off from one (1).

Table 2. Percentages of selected fish observations in submerged drydock area.

	Air On	Air Off	Percent Change [1-(on\off)]
Percent of Total Observations - All Tests	11%	89%	87% Reduction
Percent of Total Observations 4/25 and 9/1 Results Excluded	35%	65%	46% Reduction
Percent of Total Observations 4/25 Results Only	60%	40%	53% Increase
Percent of Total Observations 9/1 Results Only	8%	92%	92% Reduction

The ratios for three of the four sets of observations show there were fewer fish observations as a percentage of the total observations with the air curtain on. The observation sets also show reductions in the number of fish observations ranging from 46 percent to 92 percent with the air curtain on versus off. Observation sets for April 25th show a higher percentage of fish observations with the air curtain on, and an increase in the number of observations with the air curtain on versus off. The majority of the non-salmonid fish observed on April 25th were black crappie.

Table 3 summarizes the number of salmon and steelhead observations, versus other fish species observed in the surveys. American shad observations are also shown separately as this species is anadromous and may be a suitable surrogate for salmonids, and was observed in significant numbers on one test date.

Table 3. Selected fish observations by type, and the percent change in observations with the air curtain on versus off.

		Air On	Air Off	Percent Change
All Tests	Salmon/Steelhead	6	26	77% Reduction
	American Shad	59	726	92% Reduction
	Other Species	34	15	127% Increase
Results for 4/25 and 9/1 Excluded	Salmon/Steelhead	3	16	81% Reduction
	American Shad	0	0	
	Other Species	10	6	67% Increase
Results for 4/25 Only	Salmon/Steelhead	3	10	70% Reduction
	American Shad	0	0	
	Other Species	23	9	156% Increase

The number of salmon and steelhead observations was lower in all tests with the air curtain on relative to when it was not in use. Fish observations classified as other species during testing on April 25th represent nearly 68 percent of the total other species observations. Nighttime testing was only performed on April 25th.

Water Velocity During Drydock Flooding

The normal submergence rate of drydock 4 is approximately 1.5 feet per minute. Water flowing onto the deck was measured at velocities well above 0.4 feet per second (fps) until the water depth on the drydock reached approximately 22 feet. The slow submergence rate was approximately 0.3 foot per minute until a water depth of 7 feet was achieved, then it was increased to 0.5 foot per minute until a water depth of 14 feet was achieved, and then increased again to 1.5 feet per minute until a water depth of 25 feet was achieved. Water velocities onto the drydock were measured at or below 0.4 fps throughout the slow submergence.

The effects of submergence rate are most apparent by comparison of American shad observations during tests 12, 13, and 14, conducted on September 1st. Large numbers of American shad were present in the harbor during these tests. The juvenile fish were uniform in size, measuring from 2.5 to 3 inches in length. Table 4 summarizes the test observations.

Table 4. Comparison of American shad observations at slow and normal drydock submergence rates.

	Shad	Submerge Rate	Air Curtain
Test Number			
12	18	Slow	On
13	726	Normal	Off
14	41	Normal	On

Test number 12 combined the air curtain with a slow submergence rate, and was the first test performed for the day. Test number 13 was performed without the air curtain at a normal submergence rate, immediately following test number 12. Test number 14 was performed with the air curtain on at a normal submergence rate for comparison with test number 12. Based on this comparison, there was a 56 percent reduction in fish observations using a slow submergence rate.

PRELIMINARY CONCLUSIONS

The following preliminary conclusions are based on the findings of the 14 observations to date.

- The air curtain screen appears to be an effective barrier for deterring certain species of fish from entering a submerged drydock area. Chinook salmon and American shad observations were lower in all tests and on each day of testing when the air curtain was operating. Conversely, the air curtain does not appear effective at repelling some species of fish. In the testing to date, this appears to apply to panfish (black crappie).

- A slow drydock descent rate appears to reduce the overall number of fish that pass through the air curtain. This is particularly applicable to juvenile fish. The appropriate descent rate will likely be particular to a specific drydock, as will the appropriate approach velocity. The target approach velocity of 0.4 fps used for this study was derived from guidance provided by the NMFS, and is intended to protect emergent-size salmonid fry from impingement on screens. Development of site specific approach velocities for application to floating drydock descent rates may be less restrictive and more conducive to operations, yet provide adequate protection for juvenile fish.

- A significant amount of test data is necessary to conclusively evaluate the efficacy of the air curtain screen, or any other barrier system, for application on a floating drydock. At this study site the applicability and quality of the test results are highly dependent upon the migratory patterns and life stages of the target species. Variability in the response to the air curtain between species, and within species

under different environmental conditions, make it difficult to extrapolate data across tests.

RECOMMENDATIONS

1. Conduct a minimum of 20 additional tests. The tests should be timed to coincide with the juvenile migration periods of target species to maximize the number of observations.

2. Review the feasibility of using juvenile American shad as a surrogate for juvenile salmonids. This is principally due to their abundance in the Willamette system relative to other anadromous species.

3. Evaluate the effects of environmental conditions on fish response to the air curtain. This should include comparative testing during daylight and at night, and consideration of the effects of drydock lighting.

4. Further evaluate the effects of water approach velocities and corresponding drydock descent rates.

5. Evaluate the effects of augmenting the air curtain system with sonics to deter target and other species.

Appendix A-1: Fish Observations During Air Curtain Field Testing
All Tests

Date	Test Number	Common Name	Count	Air	Submerge Rate
4/11/00	1	Chinook Salmon	1	On	Normal
	1	Smallmouth Bass	1	On	Normal
	1	Crappie	3	On	Normal
4/11/00	2	No fish	0	Off	Normal
	2	Bluegill	1	Off	Normal
	2	Smallmouth Bass	1	Off	Normal
4/12/00	3	Chinook Salmon	5	Off	Normal
4/12/00	4	No fish	0	On	Slow
4/13/00	5	Chinook smolt observed	1	On	Normal
4/13/00	6	Chinook Salmon	6	Off	Normal
4/20/00	7	Chinook Salmon	2	Off	Slow
	7	Chinook smolt observed	1	Off	Slow
	7	Chinook Salmon	2	Off	Slow
	7	Crappie	2	Off	Slow
	7	Yellow perch	1	Off	Slow
	7	Unknown	1	Off	Slow
4/20/00	8	No fish	0	On	Normal
	8	Steelhead adult observed	1	On	Normal
	8	Bluegill	6	On	Normal
4/25/00	9	Crappie	9	On	Slow
	9	Sun fish	1	On	Slow
	9	Sculpin	1	On	Slow
	9	Smolt observed-electrofishing	1	On	Slow
	9	Steelhead Trout-electrofishing	1	On	Slow
	9	Chinook Salmon	1	On	Slow
	9	Crappie	12	On	Slow
4/25/00	10	Crappie	1	Off	Normal
	10	Chinook Salmon	2	Off	Normal
	10	Crappie	1	Off	Normal
	10	Steelhead trout	1	Off	Normal
	10	Chinook Salmon	6	Off	Normal
	10	Peamouth	1	Off	Normal
	10	Carp	1	Off	Normal
	10	Bluegill	1	Off	Normal
	10	Peamouth	1	Off	Normal
	10	Sculpin	1	Off	Normal
	10	Chinook Salmon	1	Off	Normal
6/25/00	11	Unidentified	1	Off	Normal
	11	Carp	1	Off	Normal
9/1/00	12	American Shad	18	On	Slow
9/1/00	13	American Shad	726	Off	Normal
9/1/00	14	American Shad	41	On	Normal
	14	Smallmouth Bass	1	On	Normal
		Total	**866**		

Appendix A-2: Field Observations During Air Curtain Field Testing
Air Curtain On

Date	Test Number	Common Name	Count	Air	Submerge Rate
4/11/00	1	Chinook Salmon	1	On	Normal
	1	Smallmouth Bass	1	On	Normal
	1	Crappie	3	On	Normal
4/12/00	4	No fish	0	On	Slow
4/13/00	5	Chinook smolt observed	1	On	Normal
4/20/00	8	No fish	0	On	Normal
	8	Steelhead adult observed	1	On	Normal
	8	Bluegill	6	On	Normal
4/25/00	9	Croppies	9	On	Slow
	9	Sun fish	1	On	Slow
	9	Sculpin	1	On	Slow
	9	Smolt observed-electrofishing	1	On	Slow
	9	Steelhead Trout-electrofishing	1	On	Slow
	9	Chinook Salmon	1	On	Slow
	9	Crappie	12	On	Slow
9/1/00	12	Shad	18	On	Slow
9/1/00	14	Shad	41	On	Normal
	14	Bass	1	On	Normal
		Total	**99**		

Appendix A-3: Fish Observations During Air Curtain Field Testing
Air Curtain Off

Date	Test Number	Common Name	Count	Air	Submerge Rate
4/11/00	2	Bluegill	1	Off	Normal
	2	Smallmouth Bass	1	Off	Normal
4/12/00	3	Chinook Salmon	5	Off	Normal
4/13/00	6	Chinook Salmon	6	Off	Normal
4/20/00	7	Chinook Salmon	2	Off	Slow
	7	Chinook smolt observed	1	Off	Slow
	7	Chinook Salmon	2	Off	Slow
	7	Croppie	2	Off	Slow
	7	Yellow perch	1	Off	Slow
	7	Unknown	1	Off	Slow
4/25/00	10	Croppie	1	Off	Normal
	10	Chinook Salmon	2	Off	Normal
	10	Crappie	1	Off	Normal
	10	Steelhead trout	1	Off	Normal
	10	Chinook Salmon	6	Off	Normal
	10	Peamouth	1	Off	Normal
	10	Carp	1	Off	Normal
	10	Bluegill	1	Off	Normal
	10	Peamouth	1	Off	Normal
	10	Sculpin	1	Off	Normal
	10	Chinook Salmon	1	Off	Normal
6/25/00	11	Unidentified	1	Off	Normal
	11	Carp	1	Off	Normal
9/1/00	13	Shad	726	Off	Normal
		Total	**767**		

Appendix B: Fish Observation Ratio Calculations

All Tests

Air		Ratios	Change
On	99	99\866 = .11	
Off	767	767\866 = .89	1 - (99\767) = .87
	866		

4/25/00 Results Excluded

Air	4/25	Balance	Ratios	Change	
On	26	73	73\823 = .09	1 - (26\17) = .53	4/25
Off	17	750	750\823 = .91	1 - (73\750) = .90	Balance
	43	823			

9/1/00 Results Excluded

Air	9\1	Balance	Ratios	Change	
On	60	39	39\80 = .49	1 - 60\726) = .92	9/1
Off	726	41	41\80 = .51	1 - (39\41) = .05	Balance
	786	80			

4/25/00 and 9/1/00 Results Excluded

Air	4/25,9/1	Balance	Ratios	Change
On	86	13	13\37 = .35	
Off	743	24	24\37 = .65	1 - (13\24) = .46
	829	37		

Salmon/Steelhead Observations

All Tests

	Air On	Air Off	Change	
Salmon/Steelhead	6	26	1 - (6\26) = .77	
American shad	59	726	1 - (59\726) = .92	
Other	34	15	1 - (34\15) = 1.27	increase

4/25/00 and 9/1/00 Results Excluded

	Air On	Air Off	Change	
Salmon/Steelhead	3	16	1 - (3\16) = .81	
American shad	0	0		
Other	10	6	1 - (10\6) = -.67	increase

4/25/00 Results

	Air On	Air Off	Change	
Salmon/Steelhead	3	10	1 - (3\10) = .70	
American shad	0	0		
Other	23	9	1 - (23\9) = 1.56	increase

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